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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

AERODYNAMIC AND HYDRODYNAMIC CHARACTERISTICS OF MODELS OF SOME AIRCRAFT-TOWED MINE-SWEEPING DEVICES

TED NO. NACA AR 8201

By Robert E. Shanks

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SUMMARY

As part of a study by the Naval Air Development Center to determine the feasibility of several airborne magnetic mine-sweeping systems, an experimental investigation has been conducted at the Langley Laboratory using small-scale models to determine the aerodynamic and hydrodynamic towing characteristics of three of the proposed methods. These methods have been designated the double Q-sweep (which consists of two electrical coils towed in tandem from one aircraft with both coils being at the same altitude), the modified double-catenary sweep (which consists of an electrical circuit formed by two cables of different lengths carried between two aircraft flying side by side with the lowest point of each cable at the same altitude), and the M-sweep (which consists of an electrical circuit formed by one cable carried between two aircraft flying side by side and a submerged electrode towed from each aircraft, the circuit being completed through the water between the electrodes).

The tests of the double Q-sweep method indicated that the aerodynamic towing behavior of the coil was satisfactory but that if the coil struck the water inadvertently it would dig in. Both the aerodynamic and hydrodynamic characteristics were satisfactory when the coils were equipped with a hydro-ski and a vertical fin. The tow behavior was satisfactory when the drag of the rear coil was increased (to make it trail behind the front coil) by adding a parachute, or a conical drogue or by increasing the cross-sectional area of the coil.

Qualitative results for the modified double-catenary and the M-sweep methods show that the tow characteristics of the catenary cables

or the electrodes would be satisfactory, but that the electrodes of the M-sweep would not remain submerged at the desired depths at speeds greater than 15 knots, full scale, even when streamlined weights of practical size were added.

INTRODUCTION

A study is being conducted by the U. S. Naval Air Development Center to determine the feasibility of several airborne magnetic mine-sweeping methods. The advantages of a satisfactory airborne method are greater safety and speed than are possible with existing surface methods.

As part of this study an experimental investigation has been conducted in several of the Langley Laboratory facilities to determine the aerodynamic and hydrodynamic characteristics of three proposed aircraft-towed mine-sweeping devices. The three configurations investigated are described in some detail in reference 1 where they are designated as the double Q-sweep, the modified double-catenary sweep and the M-sweep. The essential features of these configurations are shown in figure 1.

The aerodynamic characteristics were investigated in the Langley free-flight tunnel and, to a limited extent, in the Langley full-scale tunnel. The hydrodynamic tests were made in the Langley tank no. 1.

MODELS AND APPARATUS

Q-Sweep

The coils used in this Q-sweep investigation were 1/20-scale models of the full-scale coils. The basic coil was made of aluminum wire and a coil of larger cross-sectional area was made of balsa. Each of the coils was equipped with a square vertical fin and a hydro-ski. The hydro-ski plan form was rectangular except for the trailing edge which tapered to a point. The dimensions and weights of these coils, hydro-skis, and fins are given in table I.

A parachute and a drogue were also used with the basic coil. The parachute had a preformed hemispherical canopy which was made of a silk fabric having a porosity of 432 (cubic feet of air that will pass through 1 square foot of cloth per minute under a pressure of 1/2 inch of water). It had been previously established that this parachute was stable by itself. The drogue was a paper cone which had an apex angle of 50°. The cone had two balsa bulkheads to keep it from collapsing in the airstream and the paper was waxed to make it water resistant. The pertinent dimensions of the parachute and drogue are given in table I. A sketch illustrating the basic coil with fin, hydro-ski, parachute, and drogue is shown in figure 2.

The coils were fastened to the towline by bridles consisting basically of three 17-inch lines. In order to obtain asymmetric coil configurations for some of the tests, one of the front bridle arms was shortened to give the desired sidewise tilt. The towline and bridle were 3/64-inch (1 inch, full scale) diameter lacing cord. Towline lengths of about 12 feet, 17 to 32 feet, and 75 feet were used in the free-flight tunnel, tank no. 1, and full-scale tunnel tests, respectively. These towline lengths corresponded to full-scale towlines of 240, 340 to 640, and 1,500 feet, respectively.

Modified Double-Catenary Sweep

An 0.04-inch-diameter plastic-covered copper wire was used to represent the full-scale catenary cables which are 0.586-inch-diameter aluminum cables. The scale was 1/14.6 based on the ratio of these wire diameters. The test cable was 18 feet long, representing a full-scale cable 260 feet long. The ends of the test cable were attached to the front screen of the tunnel 6 feet apart. Two sizes of conical paper drogues were used with this wire catenary. Both had apex angles of about 60°; the smaller had a base diameter of $1\frac{3}{4}$ inches and the larger had a base diameter of $2\frac{3}{4}$ inches (2.2 feet and 3.4 feet, full scale, respectively). For the hydrodynamic tests a piece of 1/8-inch steel cable was used to represent a catenary loop.

M-Sweep

The electrode used in the hydrodynamic tests was approximately a 1/6-scale model of the proposed configuration. The electrode and towline were simulated by 22.5 feet of 1/8-inch-diameter wire. The first 10 feet of the rod represented the towline and the last 12.5 feet represented the electrode. The steel rod was towed by a 3/32-inch-diameter cotton line which was attached to a strut about 6 inches above the water.

Three streamlined lead weights were provided which could be slipped over the electrode. The weights had a parabolic shape with a fineness ratio of 5 and weighed 1.33, 2.92, and 5.90 pounds corresponding to full-scale weights of 314, 630, 1,270 pounds, respectively.

The depth of the electrode was measured visually by comparing it with markings on a streamlined strut which extended into the water near the position of the weights. The depths measured in this manner are believed to be accurate to within ±1 inch.

TESTS

The tests were made in three NACA facilities: Langley free-flight tunnel (FFT), Langley tank no. 1, and Langley full-scale tunnel (FST). These facilities are described in references 2, 3, and 4, respectively. The aerodynamic tow characteristics of all the Q-sweep coil configurations were investigated in the free-flight tunnel where the length of the tow lines was necessarily short. The behavior of two coil configurations, the basic coil with the hydro-ski, fin, and drogue and the balsa wood coil with the hydro-ski and fin were checked in the Langley full-scale tunnel for very long towlines. Tests to determine the behavior of the coil configurations in contact with water surface were made in tank no. 1. All the configurations were tested in smooth water. The basic coil with hydro-ski and fin was also tested in waves up to about 0.3 foot high and 12 feet long corresponding to full-scale waves 7 feet high and 240 feet long. The free-flight tunnel double Q-sweep tests were made at airspeeds corresponding to full-scale speeds up to 155 knots with all of the comparisons being made for a speed of 109 knots, full scale. The tank tests and full-scale tunnel tests were made at speeds corresponding to 106 and 126 knots, full scale, respectively.

Most of the aerodynamic tests were made in the free-flight tunnel at towline lengths of 12 feet to study the tow characteristics in air. All the configurations which were found satisfactory in these tests were also tested in tank no. 1 to determine their hydrodynamic properties. The aerodynamic behavior for many of the configurations was confirmed up to towline lengths of 32 feet because the models were towed in air until the towing carriage reached the test speed.

The modified double catenary tests were made at speeds corresponding to about 100 knots, full scale, in the free-flight-tunnel tests and about 50 knots, full scale, in the tank no. 1 test, and the towed electrode was tested through a speed range up to about 36 knots, full scale.

RESULTS AND DISCUSSION

A film supplement is available from NACA Headquarters, Washington, D. C., in which the results of the Q-sweep tests and the catenary-sweep tests are illustrated more clearly than is possible in the discussion in this paper.

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The tests were made primarily to determine the stability characteristics and for this purpose the results are believed to be representative of the full-scale behavior. Quantitative comparisons of the towline angles of some of the model configurations are also presented but, although these numbers are indicative of the model conditions, they may not be directly applicable to the full-scale conditions because the Reynolds numbers of some of the configurations are in the critical range where large changes in drag coefficient occur. This may result in appreciably different tow angles than indicated by the model results.

Q-Sweep

The results of the tests of the Q-sweep configurations are summarized in table II. In general, the results are presented for the behavior in the air and in smooth water. The one configuration tested in rough water is discussed separately.

Basic coil.- The tow behavior of the basic coil was satisfactory at towline lengths of about 12 feet in the free-flight tunnel. The turbulence of the tunnel airstream caused occasional movement of the coil but the coil steadied quickly following these disturbances. The hydrodynamic characteristics of this configuration were considered to be unsatisfactory. Although the coil skimmed along smoothly when barely touching the water, when it was disturbed the coil dug into the water and flipped out violently.

A hydro-ski was mounted on the front of the coil to improve the water behavior but it caused aerodynamic instability. The coil rotated about the towline axis so that the hydro-ski moved through an arc of about 90° each side of the desired position and the coil itself had a lateral oscillation with a constant amplitude of about 4 coil diameters. The addition of the fin stabilized the coil and kept the hydro-ski in the desired position. The towline angle for this configuration was about 50° to the horizontal at a test speed corresponding to 109 knots and the hydro-ski was mounted so that it had an angle to the horizontal of about 27°. The hydrodynamic behavior of this configuration was considered satisfactory in smooth water because, when the coil was deliberately dropped from a height of about 6 inches (10 feet, full scale), the hydro-ski skipped a few times and then planed smoothly.

Rough-water tests.- A few tests were made to determine the effect of waves on the behavior of the basic coil with the ski and fin. When the configuration with the hydro-ski at 27° to the horizontal was lowered to the surface of the rough water, the hydro-ski hit the waves causing the coil to bounce and to pitch about the bridle apex with the bridle lines occasionally going slack. Since this pitching motion caused changes in the angle of the hydro-ski with the horizontal, the hydro-ski occasionally hit a wave at a very shallow or negative angle and dug into the water. The resulting sudden increase in drag flipped the coil out of the water violently. This behavior was considered unsatisfactory.

When the hydro-ski angle with the horizontal was increased to about 45° the hydro-ski skipped along the wave crests with some bouncing but without digging in or without any other violent reaction. This behavior was considered satisfactory. The coil was tested in smooth water with the same hydro-ski angle and the behavior was as good as it had been with the 27° angle.

Coils with increased drag.- Because in the double Q-sweep, one coil must trail some distance behind the other, tests were made in which the drag of the rear coil was increased by adding a parachute, or a drogue, or by increasing the cross-sectional area of the coil. On the basis of the tests of the basic coil which indicated a towline angle of about 44°, a towline angle of about 25° would be required to make the rear coil tow 1,000 feet behind the front coil. Since the drag coefficient of the coils may be affected considerably by Reynolds number, no attempt was made to provide towline angles of exactly 25° for the increased drag configurations. It was only intended that the drag of these models approximate the desired drag closely enough that their stability characteristics would be representative of possible rear coil configurations.

The parachute reduced the towline angle to about 18° to the horizontal at a test airspeed corresponding to 109 knots, full scale, when it was attached either to the apex of the bridle or to the coil at the fin. With the parachute attached directly to the coil, the coil was steady both with and without the fin. Evidently the stability provided by the parachute was large relative to that of the fin so that the absence of the fin was not apparent in the behavior of the coil. The hydrodynamic properties of this configuration were satisfactory. The aerodynamic behavior of the configuration with the parachute attached to the apex of the bridle was not as good as that with the parachute attached directly to the coil because the coil swung from the apex of the bridle with a lightly damped motion when it was disturbed.

The drogue which was used to increase the drag of the coil produced a towline angle of about 25° to the horizontal. With the drogue attached directly to the coil at the fin, the coil towed quite steadily with no noticeable change in behavior at towline lengths of 12, 32, and 75 feet. This coil configuration was considered satisfactory on the water because it planed smoothly on the hydro-ski.

The third means of increasing the drag was to increase the cross-sectional diameter of the coil without increasing its weight. The towline angle of this coil configuration was about 30° to the horizontal.

With the hydro-ski and fin this configuration towed steadily at towline lengths of 12 and 75 feet and was as satisfactory as the parachute or drogue configurations. The hydrodynamic characteristics of this configuration were also satisfactory.

Unsymmetrical coil configurations.- The calculations of the sweeping effectiveness of towed coils reported in reference 1 indicate the presence of "holidays" (regions of reduced effectiveness) which could be eliminated by tilting the coils sideways to introduce asymmetry in the horizontal electrical field. Accordingly, some tests were made to determine the effect on the aerodynamic and hydrodynamic tow characteristics of tilting the coils by shortening one of the forward bridle arms about 30 percent. On the basic coil configurations with hydro-ski and fin, with hydro-ski, fin, and parachute, and with hydro-ski, fin, and drogue the aerodynamic behavior appeared to be the same as with the coil tilted forward only. In spite of the asymmetry of these configurations, the coils appeared to tow almost straight back.

The balsa coil was tested in the Langley free-flight tunnel with the front right bridle arm shortened 10, 17, and 30 percent and in Langley tank no. 1 with the front right bridle arm shortened 10 percent. The coil towed steadily with the bridle arms shortened 10 and 17 percent, but when the arm was shortened 30 percent the coil became unstable and moved in a circular path at speeds above 90 knots, full scale. With the bridle arm shortened 10 percent the towline made an angle of about 12° with the direction of motion. The tow behavior of the coil was satisfactory on the water in the configuration with the bridle arm shortened 10 percent. The configuration was not tested in the tank no. 1 with the bridle shortened 17 percent.

Modified Double-Catenary Sweep

The results presented for this sweep configuration are qualitative because the wire used to simulate the catenary loops represented the full-scale wire as to density but not as to length. The scale based on the wire diameters was 1/14.6 which means that in the tests only a 260-foot loop was represented.

The wire assumed a catenary shape in the airstream. The behavior was considered satisfactory because the wire towed steadily except for movements resulting from occasional disturbances in the airstream. The wire steadied quickly from these disturbances and resumed its normal tow position. In this sweep, the rear loop is larger than the front loop. In order for the lowest point of each loop to be at the same height as shown in figure 1(b), the longer rear loop must trail at a flatter angle than the front loop. Three evenly spaced drogues were used to increase the drag of the cable and thus reduce the droop angle of the rear cable. The variation of the droop angle of the cable with the drogue size was as follows: wire alone, 17°; wire with the $1\frac{3}{4}$-inch-diameter drogues, 10°; and wire with the $2\frac{3}{4}$-inch-diameter drogues, 5°. The loop with either the small or the large drogues appeared to be just as steady as the wire loop alone.

In these tests in which three drogues were used at a time the original catenary shape of the coil was altered only slightly. On a longer loop, it might be necessary to use a greater number of evenly spaced drogues. In one exploratory test made with only two of the larger drogues the loop assumed a trapezoidal shape. This appears to be a satisfactory approach to an airborne rectangular coil configuration which consists of a rectangular circuit formed by attaching one end of a long cable to each of the wing tips of an airplane.

One test was made in smooth water to determine the behavior of a loop in contact with the water. When the steel aircraft cable used for this test was lowered to the surface of the water, it skimmed along smoothly without any sudden motions or increases in drag. The results may be different, however, in rough water.

M-Sweep

The results of the hydrodynamic tests of the electrode consist of observations of the tow behavior and of the visual measurements of the electrode depth at various tow speeds which are presented in figure 3. In this system the electrode should be submerged to a depth of at least 18 feet, full scale. Tests with the electrode showed that it towed smoothly but surfaced at a very low speed and skimmed along on the top of the water. In an effort to hold the electrode beneath the surface as simply as possible, the streamlined weights were added to the rod at the location representing the front of the electrode.

The results presented in figure 3 show that none of the weights were successful in keeping the electrode submerged at the desired depth for speeds greater than about 15 knots, full scale, and all the configurations were at or very near to the surface at speeds of about 36 knots, full scale.

SUMMARY OF RESULTS

The results of an experimental investigation conducted to determine the tow characteristics in air and in water of three proposed magnetic-mine-sweeping systems may be summarized as follows:

1. The tests of the double-Q sweep method indicated that the aerodynamic tow behavior of the basic coil was satisfactory but that if the coil struck the water inadvertently it would dig in. Both the aerodynamic and hydrodynamic characteristics were satisfactory when the coils were equipped with a hydro-ski and a vertical fin. Because one coil must trail about 1,000 feet behind the other, several means of increasing the drag of the rear coil were investigated. The tow behavior was found to be satisfactory when the drag of the rear coil was increased by adding a parachute, or a conical drogue or by increasing the cross sectional area of the coil.

2. Qualitative results indicated that the tow characteristics of the modified double-catenary sweep would be satisfactory. It was found that the droop angle of the longer catenary could be reduced by use of conical drogues.

3. In the hydrodynamic tests of the M-sweep method the electrodes towed smoothly but rode along the surface of the water instead of remaining submerged. Although streamlined weights helped keep the electrodes submerged, the electrodes could not be kept at the desired depth at speeds greater than about 15 knots, full scale, by weights of practical size.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 1, 1955.

Robert E. Shanks

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Aeronautical Research Scientist

Approved: Thomas A. Harris

Thomas A. Harris
Chief of Stability Research Division

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2. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN 810, 1941.

3. Truscott, Starr: The Enlarged N.A.C.A. Tank, and Some of Its Work. NACA TM 918, 1939.

4. De France, Smith J.: The N.A.C.A. Full-Scale Wind Tunnel. NACA Rep. 459, 1933.

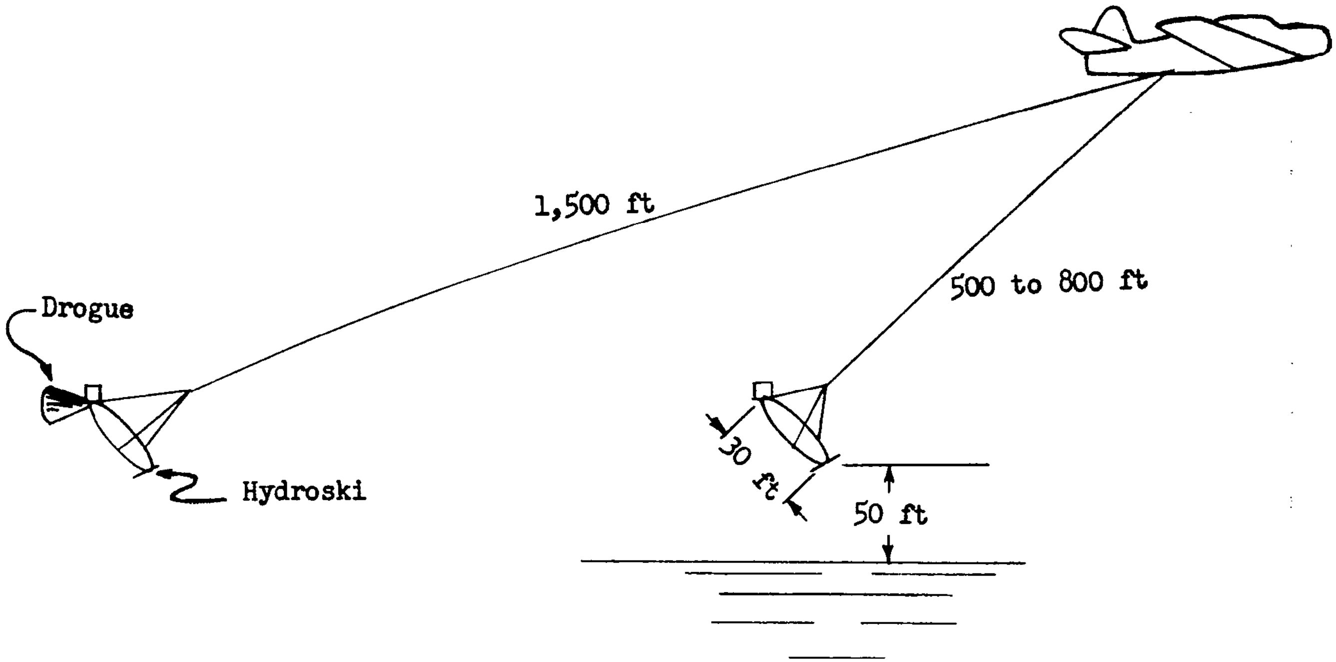
TABLE I.- DIMENSIONAL AND WEIGHT CHARACTERISTICS OF THE COMPONENTS OF THE Q-SWEEP CONFIGURATIONS

	Model	Full size
Basic coil:		
Coil diameter, ft	1.5	30
Cross-sectional diameter, ft	0.0104	0.208
Weight, lb	0.071	565
Balsa coil:		
Coil diameter, ft	1.5	30
Cross-sectional diameter, ft	0.042	0.83
Weight, lb	0.071	565
Vertical fins:		
Span and chord, ft	0.187	3.7
Weight, lb	0.018	140
Hydro-ski:		
Length, ft	0.25	5.0
Width, ft	0.062	1.25
Taper length, ft	0.083	1.7
Weight, lb	0.022	175
Parachute:		
Diameter, ft	0.82	16.5
Drogue:		
Diameter (base), ft	0.58	11.7

TABLE II.- SUMMARY OF THE TEST RESULTS FOR 1/20-SCALE MODELS OF THE Q-SWEEP CONFIGURATIONS

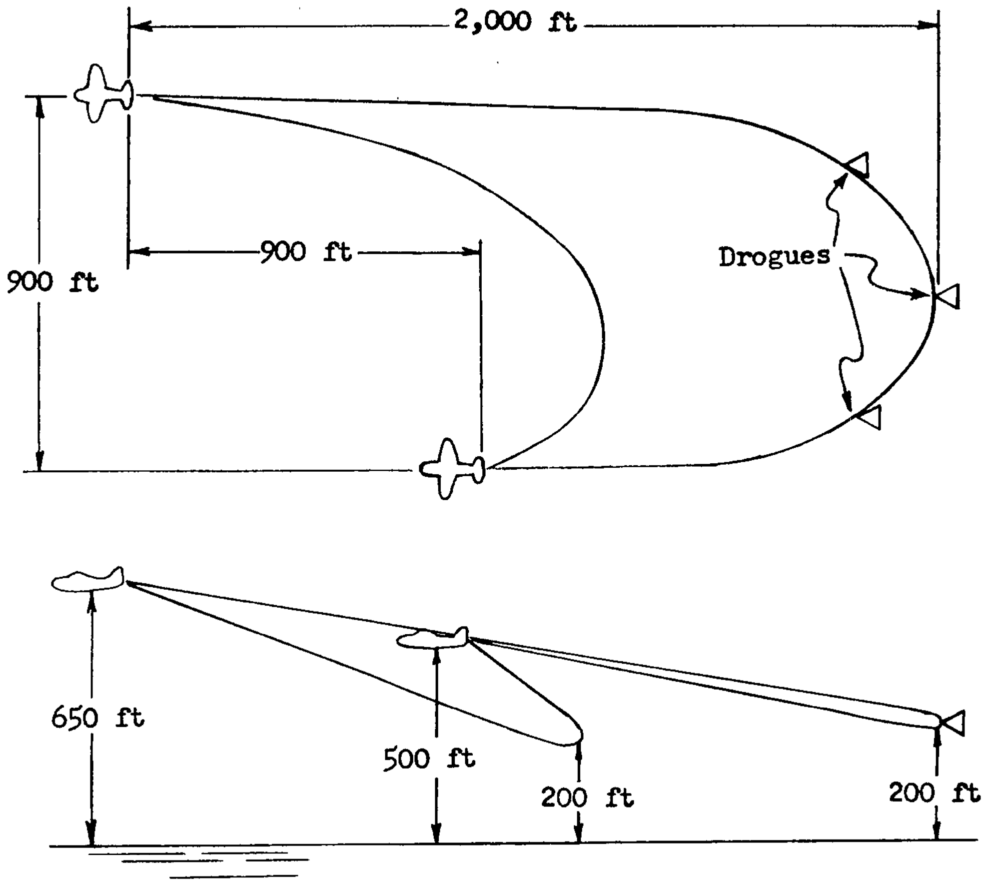
Configuration								Test facility	Results		
Coil	Hydro-ski	Vertical fin	Other	Bridle arms, Front, L, in.	Bridle arms, Front, R, in.	Bridle arms, Rear, in.	Towline length, ft		Towline angle, deg (a)	Hydro-ski angle, deg (a)	Behavior
Basic	No	No	------------------	17	17	17	12	FFT	48		Steady
Basic	No	No	------------------	17	17	17	16	Tank			Unsatisfactory - dug into water
Basic	Yes	No	------------------	17	17	17	12	FFT			Unsatisfactory - coil oscillated badly
Basic	Yes	Yes	------------------	17	17	17	12	FFT	50	27	Steady
Basic	Yes	Yes	------------------	17	17	17	17	Tank	50	27	Satisfactory on smooth water but bounced and dug into waves
Basic	Yes	Yes	------------------	17	17	17	12	FFT	44	44	Steady
Basic	Yes	Yes	------------------	17	17	17	17	Tank	44	44	Satisfactory on both smooth and rough water - bounced on waves but did not dig in
Basic	Yes	Yes	------------------	17	12	17	12	FFT	47		Steady
Basic	Yes	Yes	10-inch parachute at bridle apex	17	17	17	12	FFT	16	20	Unsatisfactory - coil easily disturbed and swung with light damping about apex
Basic	Yes	Yes	10-inch parachute at coil	17	17	17	12	FFT	18	20	Steady
Basic	Yes	Yes	10-inch parachute at coil	17	17	17	32	Tank			Satisfactory on smooth water
Basic	Yes	No	10-inch parachute at coil	17	17	17	12	FFT	18	20	Steady
Basic	Yes	Yes	10-inch parachute at coil	17	$13\frac{1}{2}$	17	12	FFT	17		Steady
Basic	Yes	Yes	Drogue	17	17	17	12	FFT	25	27	Steady
Basic	Yes	Yes	Drogue	17	17	17	75	FST			Steady
Basic	Yes	Yes	Drogue	17	17	17	32	Tank			Satisfactory on smooth water
Basic	Yes	Yes	Drogue	17	12	17	12	FFT	23		Steady
Balsa	Yes	Yes	------------------	17	17	19	12	FFT	28	20	Steady
Balsa	Yes	Yes	------------------	18	18	19	75	FST			Steady
Balsa	Yes	Yes	------------------	17	17	20	32	Tank			Satisfactory on smooth water
Balsa	Yes	Yes	------------------	18	15	19	12	FFT	29	15	Steady
Balsa	Yes	Yes	------------------	17	15	20	32	Tank			Satisfactory on smooth water
Balsa	Yes	Yes	------------------	18	12	19	12	FFT	29	15	Unsatisfactory - at about 90 knots, full scale, coil moved in circular path
Full-scale test velocities: Tank, 106 knots; free-flight tunnel, 109 knots; full-scale tunnel, 126 knots											

[a]With respect to horizontal.



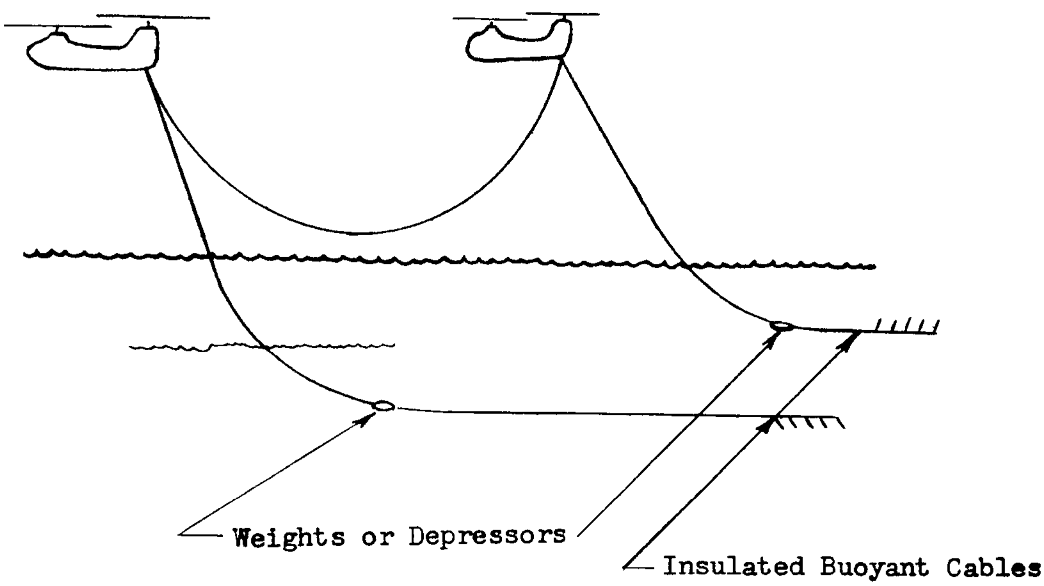
(a) Double Q-sweep.

Figure 1.- Three proposed airborne minesweeping methods.



(b) Modified double-catenary sweep.

Figure 1.- Continued.



(c) Modified M-sweep.

Figure 1.- Concluded.

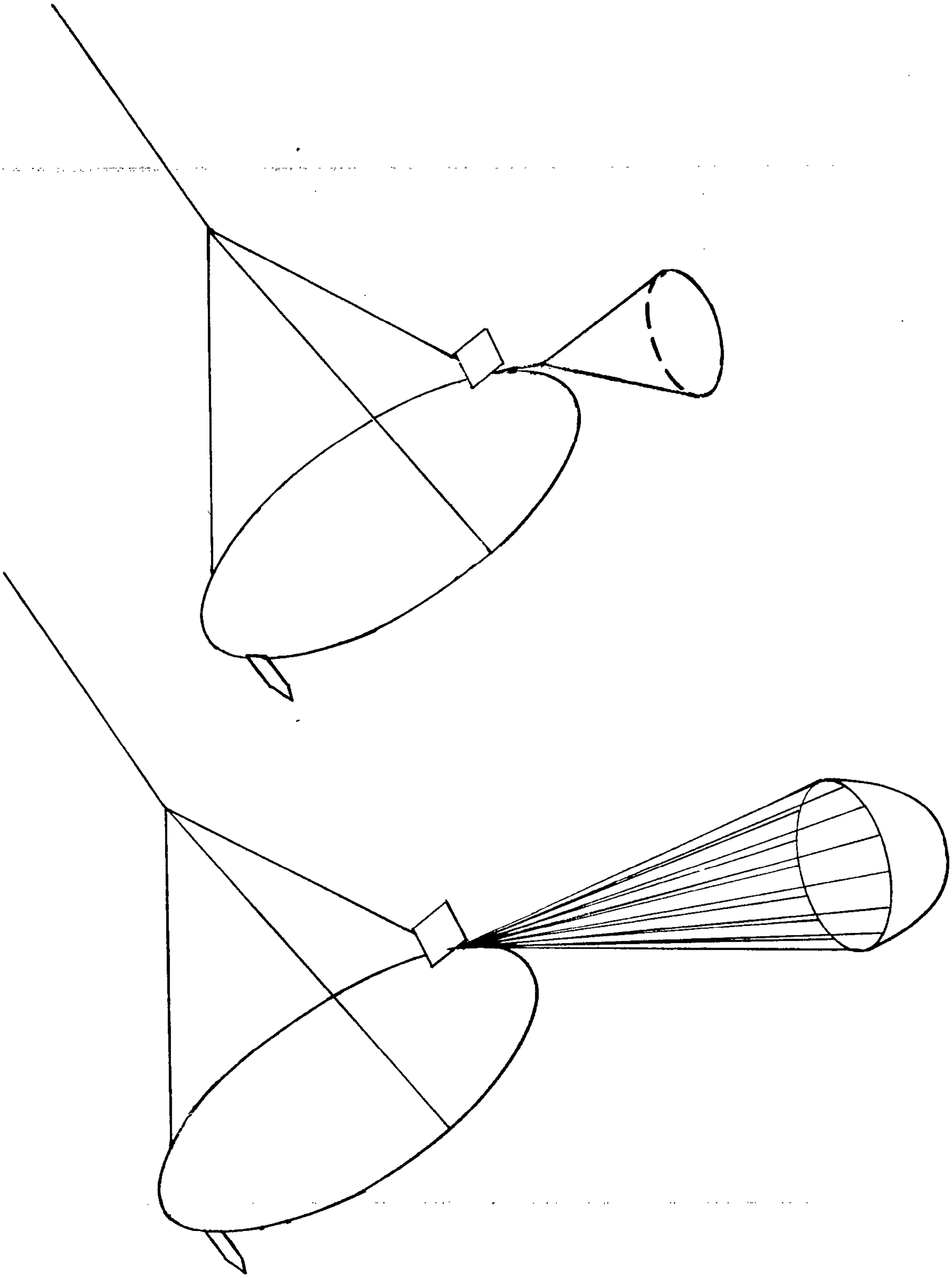


Figure 2.- Sketches of the basic coil, hydro-ski, and vertical fin with the drogue and with the parachute.

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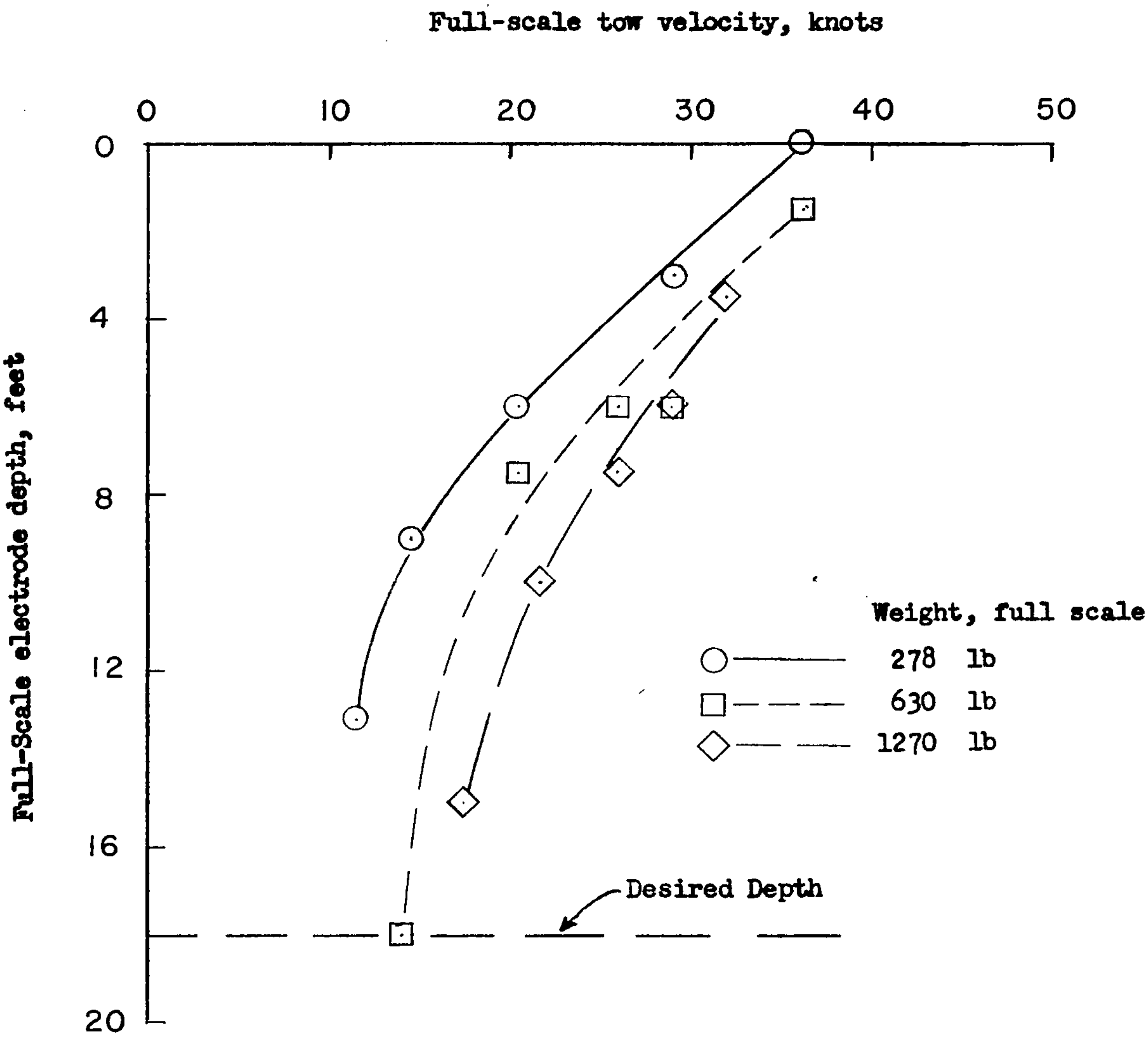

Figure 3.- Variation of electrode depth with tow velocity from model tests in tank no. 1.